CLAIMS

1. An optical waveguide for guiding light in a predefined wavelength range, the optical waveguide comprising core and cladding regions for confining light, the core and/or cladding region or regions being formed on a substrate, and the whole or a part of the core and/or cladding region or regions comprising material of the stoichiometric composition $Si_aO_xN_yX_zH_v$, wherein

X is selected from the group of elements B, Al, P, S, As, Sb and combinations thereof, and the ratio y/z is larger than 1, such as larger than 1.2, such as larger than 1.5, such as larger than 1.8, such as larger than 2.0, such as larger than 2.5, such as larger than 3.0, such as larger than 3.5, such as larger than 4.0, such as larger than 4.5, such as larger than 5.0, such as larger than 5.5, such as larger than 6.0, such as larger than 7.0, such as larger than 8.0.

2. An optical waveguide according to claim 1 wherein the ratio y/z is in the range from 1.0 to 100, such as 1.0 to 20, such as 1.0 to 10, such as 1.5 to 8.0, such as 2.0 to 4.0, such as 2.5 to 3.5.

3. An optical waveguide according to claim 1 or 2 wherein the number a defining the relative concentration of the element Si is in the range from 0.1 to 3.5 such as in the range from 0.9 to 1.1 or in the range from 2.9 to 3.1.

4. An optical waveguide according to any one of claims 1-3 wherein the number x defining the relative concentration of the element O is in the range from 0 to 2.5 such as in the range from 1.9 to 2.1 or in the range from 0 to 0.1.

5. An optical waveguide according to any one of claims 1-4 wherein the number y defining the relative concentration of the element N is in the range from 0 to 4.5 such as in the range from 3.9 to 4.1 or in the range from 0 to 0.5, such as in the range from 0.02 to 0.3, such as in the range from 0.03 to 0.2, such as in the range from 0.04 to 0.10.

6. An optical waveguide according to any one of claims 1-5 wherein the number z defining the relative concentration of the element X selected from the group comprising B, Al, P, S, As, Sb and combinations thereof is in the range from 0 to 0.3 such as in the range from 0.005 to 0.2, such as in the range from 0.01 to 0.10.

7. An optical waveguide according to any one of claims 1-6 wherein a is in the range from 0.8 to 1.2 and x is in the range from 1.8 to 2.2 and y is in the range from 0.01 to 0.5 and z is in the range from 0.005 to 0.2.

8. An optical waveguide according to any one of claims 1-6 wherein a is in the range from 2.8 to 3.2 and y is in the range from 3.8 to 4.2 and x is in the range from 0.01 to 0.5 and z is in the range from 0.005 to 0.2.

9. An optical waveguide according to claim 1 wherein the number a defining the relative concentration of the element Si is in the range from 0.9 to 1.1, the number x defining the relative concentration of the element O is in the range from 1.9 to 2.1, the number y defining the relative concentration of the element N is in the range from 0.015 to 0.12, and the number z defining the relative concentration of the element X is in the range from 0.005 to 0.04.

10. An optical waveguide according to any one of the preceding claims wherein the optical absorption peak at λ=1508 nm due to Si:N-H bonds is smaller than 0.1 dB/cm, such as smaller than 0.05 dB/cm such as smaller than 0.01 dB/cm.

11. An optical waveguide according to any one of the preceding claims wherein the number v defining the relative concentration of the element H is such that the relative concentration v/(a+x+y+z+v) of H in $Si_aO_xN_yX_zH_v$ is smaller than 10^{-2}, such as smaller than 10^{-3}, such as smaller than 10^{-4}, such as smaller than 10^{-5}.

12. An optical waveguide according to any one of the preceding claims wherein the atomic concentration of hydrogen is larger than the atomic concentration of nitrogen and/or phosphorus.

13. An optical waveguide according to any one of the preceding claims wherein the atomic concentration of hydrogen is larger than 5 at.%.

14. An optical waveguide according to any one of the preceding claims wherein the number v defining the relative concentration of the element H is such that the concentration v/y of H relative to N is smaller than 10^{-2}, such as smaller than 10^{-3}, such as smaller than 10^{-4}.

15. An optical waveguide according to any one of the preceding claims wherein the number v defining the relative concentration of the element H is such that the concentration v/z of H relative to X is smaller than 10^{-2}, such as smaller than 10^{-3}, such as smaller than 10^{-4}, X being an element selected from the group comprising B, Al, P, S, As, Sb and combinations thereof.

16. An optical waveguide according to any one of the preceding claims wherein the element or elements X or the material $Si_aO_xN_yX_zH_v$ comprises at least 50% phosphorus such as at least 75% phosphorus such as at least 90% phosphorus, such as 100% phosphorus.

17. An optical waveguide according to any one of the preceding claims wherein the element or elements X or the material $Si_aO_xN_yX_zH_v$ comprises at least two elements X(1), X(2), ..., X(n) where n ≤ 7, selected from the group comprising B, Al, P, S, Ge, As, Sb of relative concentration z_1, z_2, ..., z_n, respectively, where $z=z_1+z_2+z_3+...+z_n$ and wherein z_1/z is larger than 0.50 such as larger than 0.75 such as larger than 0.90.

18. An optical waveguide according to claim 17 wherein n=2 and X(1) is P and X(2) is B or Ge.

19. An optical waveguide according to claim 17 wherein n=3 and X(1) is P, X(2) is B and X(3) is Ge.

20. An optical waveguide according to any one of the preceding claims wherein the waveguide core and/or cladding layers comprise material of the stoichiometric composition $Si_{(1-z)}O_{(2-y)}N_yX_z$ wherein X is an element form the group comprising B, Al, P, S, As, Sb or a combination thereof.

21. An optical waveguide according to claim 20 wherein X is P.

22 An optical waveguide according to claim 20 or 21 wherein $0 < y \leq 0.2$ and $0 < z \leq 0.1$.

23. An optical waveguide according to any of the preceding claims wherein the atomic density of silicon $N_{at}(Si)$ is in the range $4.5 \cdot 10^{21} < N_{at}(Si) < 1.3 \cdot 10^{22}$, such as in the range $5.1 \cdot 10^{21} < N_{at}(Si) < 9.1 \cdot 10^{21}$, the atomic density of oxygen $N_{at}(O)$ is in the range $9.0 \cdot 10^{21} < N_{at}(O) < 2.7 \cdot 10^{22}$, such as in the range $1.0 \cdot 10^{22} < N_{at}(O) < 1.8 \cdot 10^{22}$, the atomic density of nitrogen $N_{at}(N)$ is in the range $0 < N_{at}(N) < 2.7 \cdot 10^{21}$, such as in the range $0 < N_{at}(N) < 1.8 \cdot 10^{21}$, and the atomic density of phosphorus $N_{at}(P)$ is in the range $0 < N_{at}(P) < 1.3 \cdot 10^{21}$, such as in the range $0 < N_{at}(P) < 9.0 \cdot 10^{20}$.

24. An optical waveguide according to any one of the preceding claims wherein the core and/or cladding region comprises material having a refractive index at a wavelength of 1550 nm in the range 1.45 – 2.02, such as in the range from 1.45 to 1.60, such as in the range from 1.48 to 1.56.

25. An optical waveguide according to any one of the preceding claims wherein the optical waveguide is adapted to guide light in a wavelength range from 250 nm to 3.6 µm, such as in the range from 850 nm to 1800 nm.

26. An optical waveguide according to any one of the preceding claims wherein the optical waveguide is adapted to guide light comprising wavelengths in the range from 1260 nm to 1660 nm, such as in the range 1530-1565 nm, or in the range 1460-1530 nm, or in the range 1360-1460 nm, or in the range 1260-1360 nm.

27. An optical waveguide according to any one of the preceding claims wherein the waveguide core and/or cladding further comprises a rare earth elements selected from the group of elements comprising Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu or combinations thereof.

28. An optical waveguide according to any one of the preceding claims wherein one or more of the rare earth elements are present in molar concentrations in the range from 50 to 5000 ppm mole/mole.

29. An optical waveguide according to any one of the preceding claims wherein the core and/or cladding region further comprises one or more TE-dopant elements for controlling the thermal expansion of the waveguide.

30. An optical waveguide according to any one of the preceding claims wherein the thermal expansion of one or more of the layers constituting the core and cladding regions of the waveguide is/are adapted to the thermal expansion of the substrate by adding one or more TE-dopant elements to said one or more layers of the waveguide.

31. An optical waveguide according to claim 29 or 30 wherein said TE-dopant element or elements are selected from the group of elements comprising Al, F, Ti, or combinations thereof.

32. An optical waveguide according to any one of claims 29-31 wherein said TE-dopant element or elements are present in the core/and or cladding region or regions in molar concentrations in the range from 0 to 5%.

33. An optical waveguide according to any one of claims 29-32 wherein said dopant element or elements are present in the core/and or cladding region or regions in amounts sufficient to provide a coefficient of thermal expansion between 1×10^{-7} °C^{-1} and 15×10^{-7} °C^{-1}.

34. An optical waveguide according to any one of the preceding claims comprising a buffer material constituting a barrier between the core and cladding regions and fully or partially surrounding said core region.

35. An optical waveguide according to claim 34 wherein said buffer material is selected from the group SiO_2, Si_xN_y, such as Si_3N_4, PECVD BPSG with alternative B/P doping levels and combinations thereof.

36. An optical waveguide according to any one of the preceding claims wherein said material further comprises Ge.

37. A method of manufacturing an optical waveguide for guiding light in a predefined wavelength range, the optical waveguide comprising core and cladding regions for confining light,
the method comprising the steps of
A) providing a substrate,
B) forming a lower cladding layer on the substrate,
C) forming a core region of said optical waveguide on the lower cladding layer,
D) forming an upper cladding layer to cover the core region and the lower cladding layer;
wherein the whole or a part of said waveguide core and/or cladding region or regions comprise material of the stoichiometric composition $Si_aO_xN_yX_zH_v$ and X is selected from the group of elements B, Al, P, S, As, Sb and combinations thereof, and wherein y>z, such as larger than 1.2, such as larger than 1.5, such as larger than 1.8, such as larger than 2.0, such as larger than 2.5, such as larger than 3.0, such as larger than 3.5, such as larger than 4.0, such as larger than 4.5, such as larger than 5.0, such as larger than 5.5, such as larger than 6.0, such as larger than 7.0, such as larger than 8.0.

38. A method according to claim 37 wherein step C) comprises the sub-steps
C1) forming a core layer on the lower cladding layer,
C2) providing a core mask comprising a core region pattern corresponding to the layout of the core region of said optical waveguide, and
C3) forming core regions using the core mask, a photolithographic and an etching process.

39 A method according to claim 37 or 38 wherein a sub-step
C4) of forming a barrier layer on top of said core region pattern, and optionally on top of the lower cladding layer not covered by the core region pattern;
is inserted before step D)

40. A method according to claim 38 or 39 wherein a sub-step C0) of forming a barrier layer on top of said lower cladding layer is inserted before step C1).

41. A method according to claim 39 or 40 wherein a sub-step of annealing is inserted after said barrier forming step or steps C0) and/or C4)

42. A method according to any one ofclaims 37-41 wherein the substrate is a silicon or quartz substrate.

43. A method according to any one of claims 37-42 wherein the formation of layers on the substrate is made by plasma enhanced chemical vapour deposition.

44. A method according to claim 43 wherein a standard cluster tool CVD process chamber type PECVD-apparatus from Surface Technology Systems is used for the formation of layers on the substrate.

45. A method according to claim 43 or 44 wherein processing parameters of the PECVD-process are optimized with a view to minimizing the optical absorption around λ=1508 nm.

46. A method according to any one of claims 43-45 wherein processing parameters to be optimized include one or more of the following:

a) SiH_4 flow;
b) the N_2O flow;
c) the N_2 flow;
d) the NH_3 flow;
e) the power;
f) the pressure;
g) the temperature;
h) the frequency;
i) the flow or flows comprising the element or elements X;

47. A method according to any one of claims 43-46 wherein

a) the SiH_4 flow rate is in the range from 0 to 30 sccm, such as 10 to 30 sccm;

b) the N_2O flow rate is in the range from 0 to 1000 sccm, such as 100 to 400 sccm;

c) the N_2 flow rate is in the range from 0 to 3000 sccm, such as 1000 to 3000 sccm.

d) the NH_3 flow rate is in the range from 0 to 300 sccm, such as 150 to 250 sccm;

e) the power is in the range from 0 to 1000 W, such as 400 to 1000 W.

f) the pressure is in the range from 100 to 500 mTorr, such as 200 to 500 mTorr.

g) the temperature is in the range from 200 to 500 °C, such as 200 to 400 °C.

h) the frequency is around 380 kHz or around 13.8 MHz.

48. A method according to claim 46 or 47 wherein the X=P and in i) the PH_3 flow is provided by PH_3 diluted in N_2 or another carrier gas.

49. A method according to claim 48 wherein in i) the PH_3 flow is provided by 5% PH_3 in N_2 with a flow rate of 0 to 50 sccm such as 2 to 20 sccm.

50. A method according to claim 46 or 47 wherein X comprises P and in i) the PH_3 flow is provided by PH_3 diluted in N_2 or another carrier gas and wherein the PH_3 flow value is used as a stress optimization parameter for the core region.

51. A method according to any one of claims 43-50 wherein processing parameters of the PECVD process essentially have the following values:

a) SiH_4 flow rate 20 sccm;

b) the N_2O flow rate 100-400 sccm;

c) the N_2 flow rate 2000 sccm;

d) the NH_3 flow rate is 100 sccm;

e) the power is 700 W;

f) the pressure is 250 mTorr;

g) the temperature 350 °C;

h) the frequency is 380 kHz;

i) 5% PH_3 in N_2 flow rate 10 sccm;

52. A method according to any one of claims 46-51 wherein in step i) the flow gas is selected among the group of gases SiH_4, SiF_4, $SiCl_4$, SiF_4, Si_2H_6, SiH_2Cl_2, $SiCl_2F_2$, SiH_2F_2, N_2O, NO, N_2, NO_2, O_2, H_2O, H_2O_2, CO, CO_2, N_2O, NO, N_2, NO_2, NH_3, N_2, B_2H_6, AlH_3, PH_3, H_2S, SO, SO_2, GeH_4, AsH_3, or combinations thereof.

53. An optical waveguide obtainable by a method of manufacturing as defined in any one of claims 37-52.

54. An optical device comprising an optical waveguide as defined in any one of claims 1-36 or 53.

55. An optical device according to claim 54 comprising a branching component, such as a splitter or an arrayed waveguide grating.

56. An optical device according to claim 54 or 55 comprising an optical duplexer or triplexer.